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GUIDELINES FOR DESIGN AND CONSTRUCTION OF PRECAST PRE-TENSIONED GIRDERS FOR BRIDGES

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GUIDELINES FOR DESIGN AND CONSTRUCTION OF PRECAST PRE-TENSIONED GIRDERS FOR BRIDGES

1. INTRODUCTION

1.1 The Reinforced, Prestressed and Composite Concrete Committee (B-6) of the Indian Roads Congress was reconstituted in 2003.

1.2 In its first meeting held on 29th April, 2003, the Committee felt that in the light of the massive construction programme that was under execution in the highway sector, it was necessary to bring out guidelines on certain topics which were not adequately eovered in the existing IRC Codes and Standards. The design and construction of precast pretensioned girders for bridges was one of the topics selected. It was decided that while highlighting the special detailing requirements, the guidelines would generally be in line with IRC:18 and IRC:21 and IS:14268 with additional inputs from BS:5400, EURO and AASHTO Codes besides guidelines from British Cement Association, Portland Cement Association and Precast / Prestressed Concrete Institute where necessary.

1.3 The initial draft of the guidelines was prepared by Shri Jose Kurian and revised by Shri Vinay Gupta. The draft alongwith inputs received from Shri A.B. Saha and Shri S.A. Reddi was discussed and finalized in its meeting held on 16th and 17th September, 2005. The B-6 Committee comprised of the following personnel:

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Addl. DGBR (HQ)	*Co-Convenor*
Viswanathan, T.	*Member-Secretary*

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1.4 The draft document was approved by Bridges Specifications and Standards Committee in its meeting held on 22nd October, 2005. The dou ment was considered by IRC Council in its 176th meeting held on 12th November, 2005 in Bhubaneswar and approved with certain modific-ations. The required modifications were accord ingly carried out by the Convenor, B-6 Committee before sending the document for publication.

2. SCOPE

These guidelines cover the specific design and construction requirements pertaining to precast pre-tensioned girders, which may constitute a superstructure system. Such structural systems may comprise of precast girders in association with cast-in-situ/precast deck slab and diaphragms, spliced girder system, integral bridge, etc. These superstructures may either be simply supported or continuous. In case of continuous superstructures, the continuity may be achieved either through untensioned reinforcement at the intermediate supports or through post-tensioning.

In pre-tensioning, the tendons are prestressed before concreting and prestress

transferred to the concrete, through bond, when it attains the requisite minimum strength and maturity; whereas, in the case of post tensioning, tendons are prestressed after concrete gains the requisite minimum strength and maturity. Fig. 1 & 2 give examples of precast pre-tensioned girders made continuous over supports. Fig. 3 & 4 depict an example of a pre-tensioned girder indicating bonded and debonded tendons. Fig. 5 depicts a few possible shapes of stirrups precast girder.

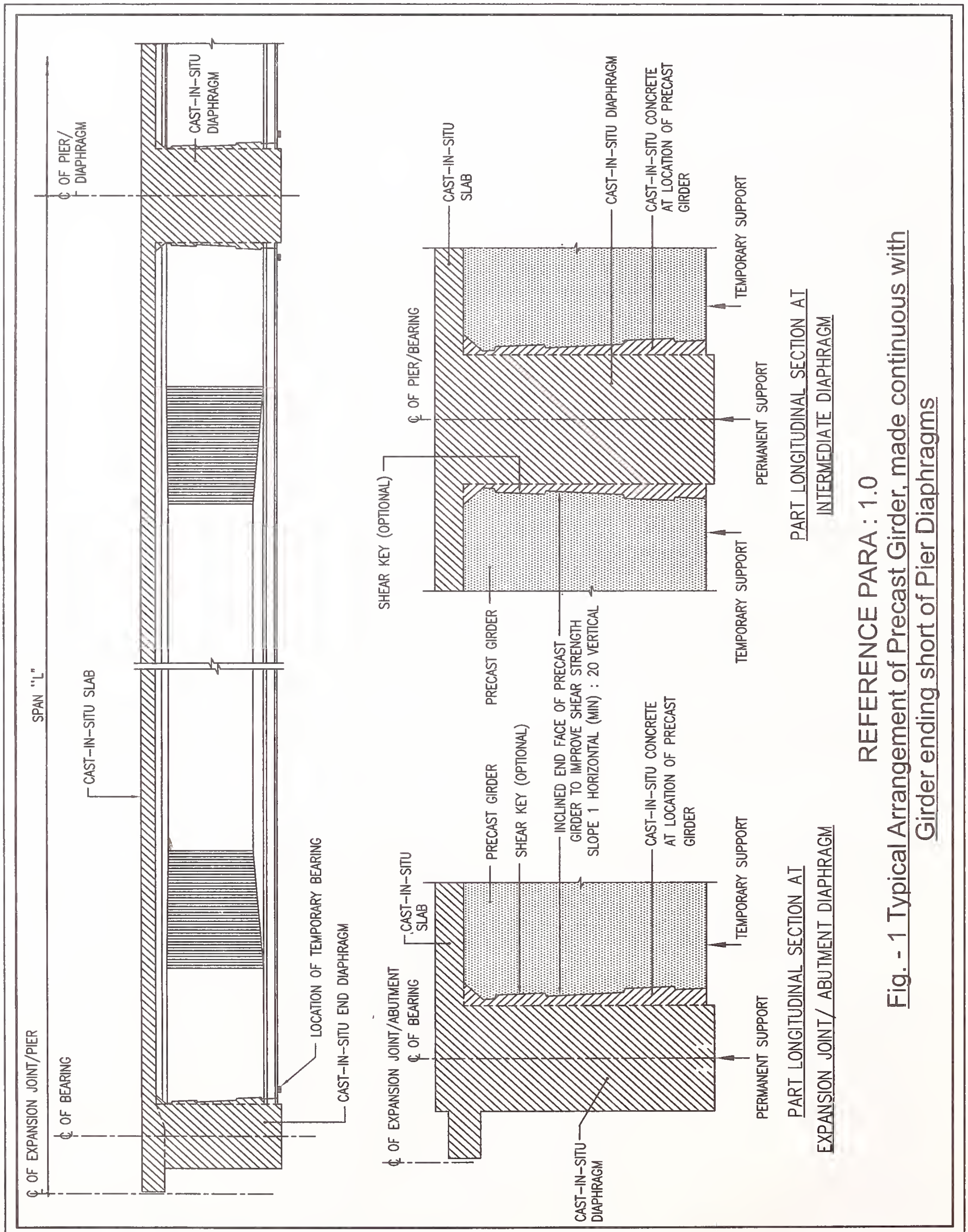
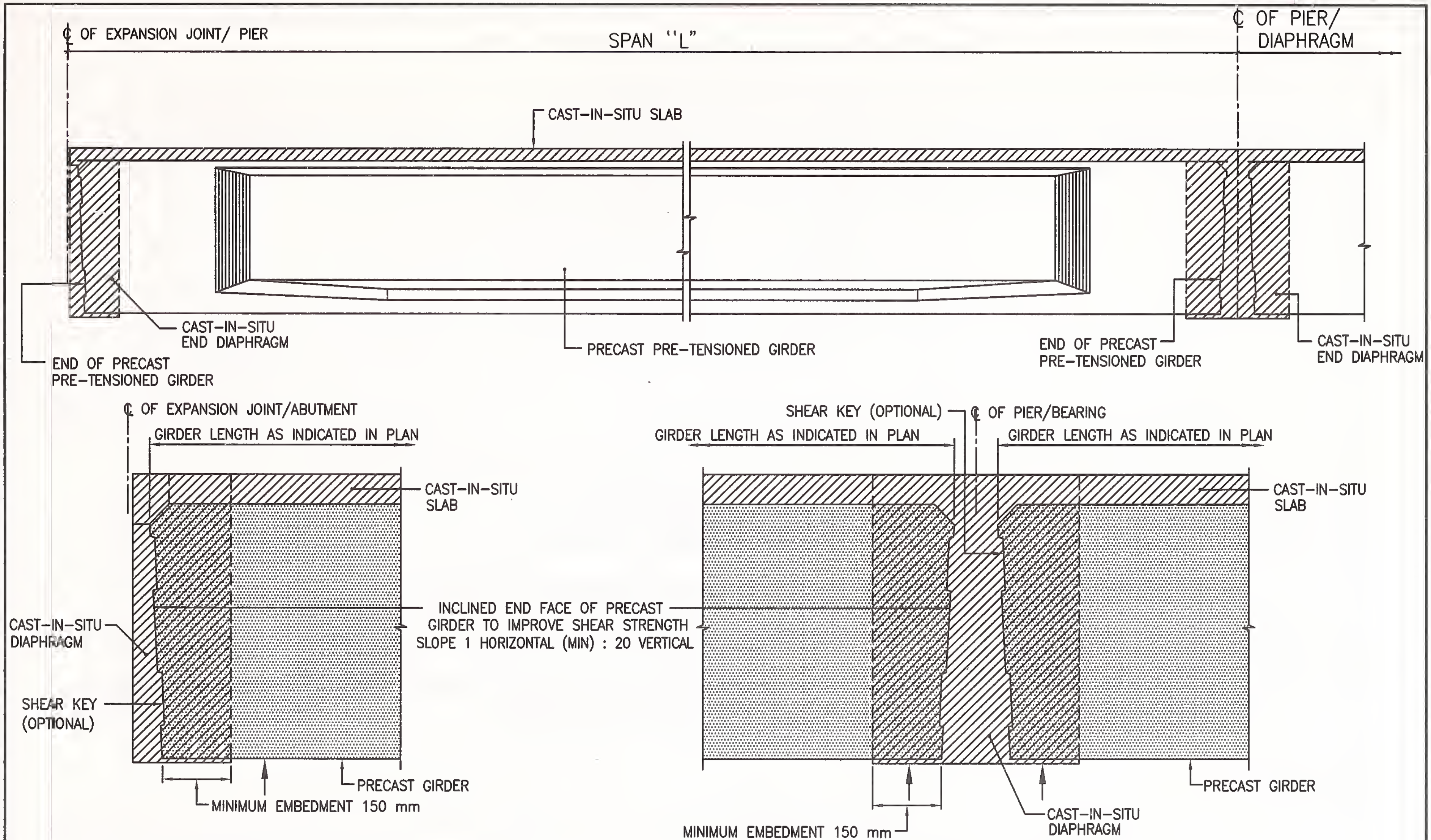


Fig. - 1 Typical Arrangement of Precast Girder, made continuous with Girder ending short of Pier Diaphragms

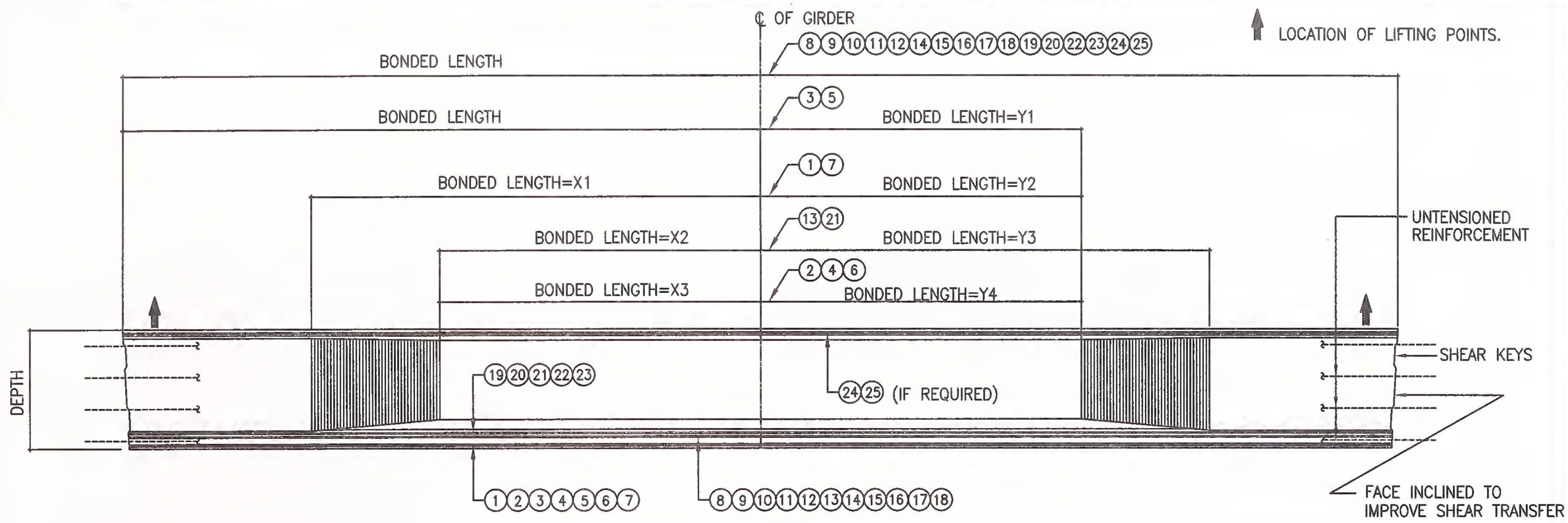


A TYPICAL PART LONGITUDINAL SECTION AT EXPANSION JOINT/ ABUTMENT DIAPHRAGM

A TYPICAL PART LONGITUDINAL SECTION AT INTERMEDIATE DIAPHRAGM

REFERENCE PARA : 1.0

Fig. - 2 Typical Arrangement of Precast Girder, made continuous with Girder Embedded in the Diaphragms



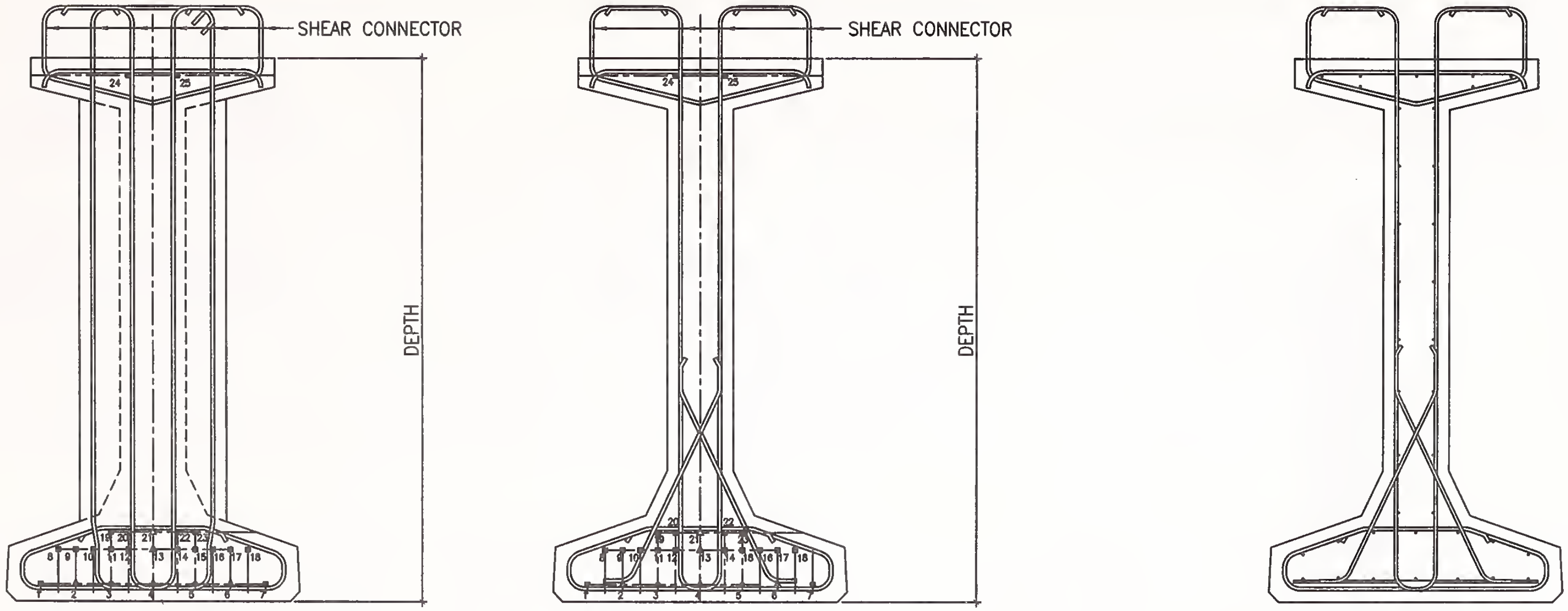
ELEVATION (SHOWING TENDONS ONLY)

TYPICAL BONDING/DEBONDING SCHEDULE

SYMBOL	STRAND NOS.	BONDING LENGTH (mm)	SCHEDULE OF BONDING & DEBONDING
■	8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20, 22, 23, 24 & 25	NO DEBONDING	FACE OF THE BEAM — BONDED LENGTH — ℄ OF BEAM/SYMM. — FACE OF THE BEAM
◓	3 & 5	VARIES	FACE OF THE BEAM — BONDED LENGTH — Y1 (BONDING) — DEBONDED — FACE OF THE BEAM
◰	1 & 7	X1+Y2	FACE OF THE BEAM — DEBONDED — X1 (BONDING) — Y2 (BONDING) — DEBONDED — FACE OF THE BEAM
△	13 & 21	X2+Y3	FACE OF THE BEAM — DEBONDED — X2 (BONDING) — Y3 (BONDING) — DEBONDED — FACE OF THE BEAM
▲	2, 4 & 6	X3+Y4	FACE OF THE BEAM — DEBONDED — X3 (BONDING) — Y4 (BONDING) — DEBONDED — FACE OF THE BEAM

REFERENCE PARA : 1.0

Fig. - 3 Typical Detail of Pretensioned Girder



A TYPICAL SECTION NEAR SUPPORT
(THICKENED WEB)

LONGITUDINAL REINFORCEMENT OF GIRDER NOT SHOWN FOR CLARITY

A TYPICAL SECTION AT MID SPAN
(REGULAR SECTION)

LONGITUDINAL REINFORCEMENT OF GIRDER NOT SHOWN FOR CLARITY

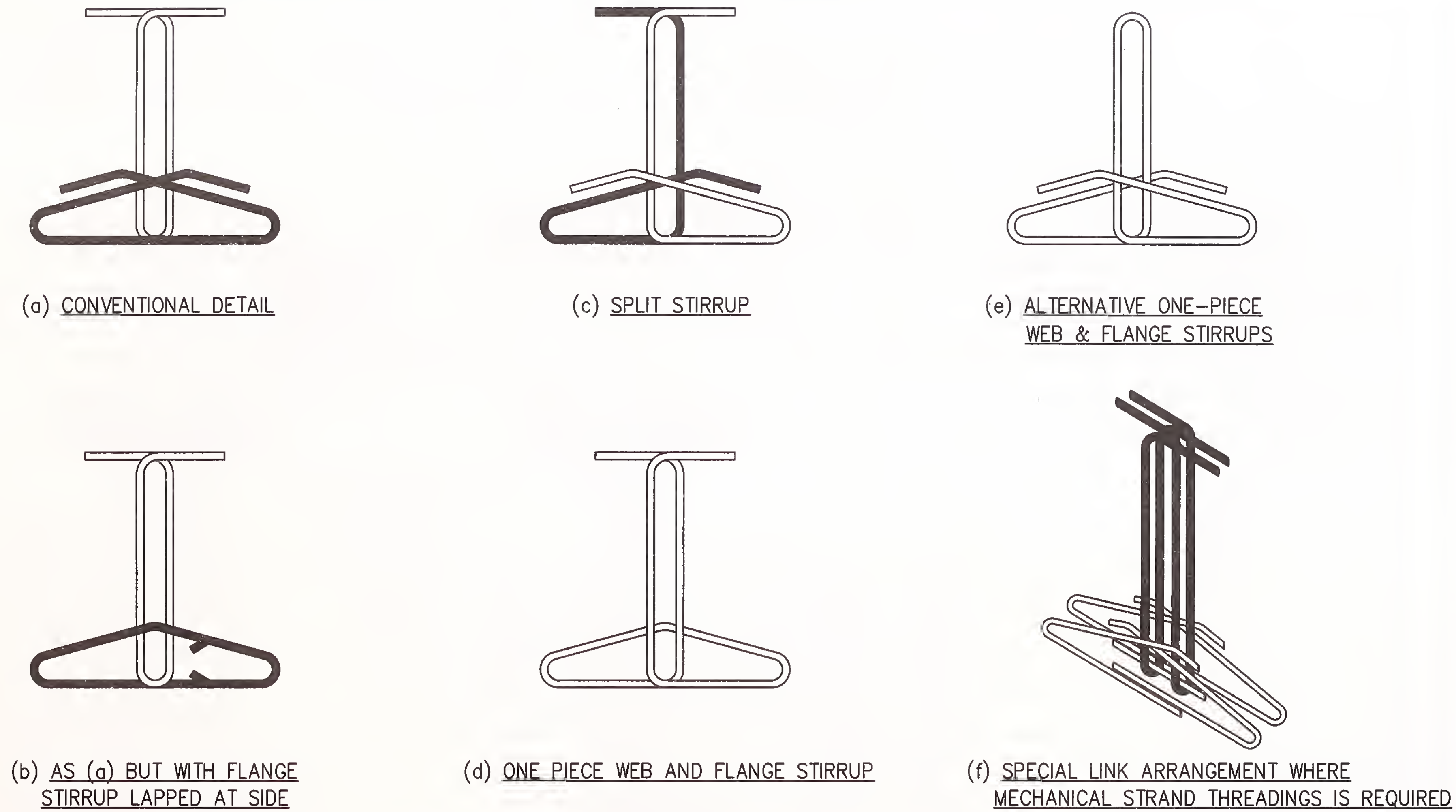
A TYPICAL SECTION AT MID SPAN
(REGULAR SECTION)

GIRDER PRESTRESS NOT SHOWN FOR CLARITY

BONDED STRANDS SUCH AS 8 TO 12, 14 TO 20 & 22 TO 25, CAN BE EMBEDDED IN CAST-IN-SITU CONCRETE OF DIAPHRAGM TO CONSTITUTE BOTTOM REINFORCEMENT OF THE GIRDER IN ADDITION TO THE HYSD REINFORCEMENT.

REFERENCE PARA : 1.0

Fig. - 4 Typical Sections of Pretensioned Girder



REFERENCE PARA : 1.0

Fig. - 5 Suggested Shapes of Stirrups in Girders

3. DESIGN REQUIREMENTS

Design shall be done in accordance with the provisions of IRC:18 except for the additional provisions and/or deviations indicated below. However, clauses 17, 19, 20, 22, and 25 of IRC:18 are not applicable to pre-tensioning.

3.1. Material Properties

Where pre-tensioned girders constitute a part of the overall structural system, which is constructed in various stages, the properties of materials used in the analysis and design shall take into account the methodology and the sequence in which the same is constructed. If the concrete strengths in two components of the composite member differ by more than 10 MPa, allowance for this shall be made in assessing stiffnesses and stresses.

3.2. Permissible Stress in Concrete

3.2.1. **Permissible Temporary Stresses in Concrete :** While the other limits shall apply as per clause 7.1 of IRC:18, the minimum strength of concrete at transfer shall be such that it satisfies stress check at all stages of construction. Minimum characteristic strength (f_{ck}) of concrete shall be M40 and minimum strength at transfer of prestress shall be 0.8 f_{ck} or 35MPa, whichever is lesser. Use of High Performance Concrete and/or steam curing may be made to achieve high early strength of concrete. In case of debonding of strands, check of stresses at the point of start of debonding shall be made by excluding the debonded strands. The debonded strands shall be taken to be fully effective at the end of transmission length. Intermediate values (arrived at by straight line interpolation from zero effectiveness at the start of bonding to full effectiveness at the end of transmission length) may be used for intermediate locations. It is, often necessary to provide a few strands at top of the precast girder also, in order to control the tensile stresses at top during handling.

3.2.2. **Permissible Stresses in Concrete During Service :** While other limits of permissible stresses remain the same as those covered in clause 7.2 of IRC:18, stresses at top of the precast girder may be allowed to go into tension at the locations where top section is designed as reinforced concrete section, which is a common practice in case of precast pretensioned girders made continuous using cast-in-situ RCC deck slab and diaphragm. However, tensile stresses at the top of precast pretensioned girder shall be limited to $0.36\sqrt{f_{ck}}$. Adequately designed untensioned reinforcement shall be provided to take care of this tension.

3.3. Minimum Dimensions

All provisions relating to minimum concrete dimensions shall be as per clause 9.3.1 of IRC:18 except for the following limitations relating to various structural components which will prevail over the corresponding values of the Code:

Thickness of top flange	: 100mm
Thickness of bottom flange	: 150mm
Thickness of web	: 150mm
Thickness of deck slab where top flanges are contiguous	: 150mm

Note : The minimum web thickness indicated above applies to 'T' and 'I' shaped girders. In case of other special types of sections, minimum web thickness may be decided on the basis of appropriate specialist literature.

3.4. Minimum Reinforcement

In order to meet the requirement of minimum untensioned steel as per IRC: 18 or IRC: 21, the available high tensile steel (bonded only) may be assumed to constitute this requirement, considering it at same strength as the untensioned steel.

3.5. Losses in Prestress

The losses due to creep and shrinkage of concrete shall be calculated in the manner stipulated in IRC: 18, taking due account of various stages of loading. Losses due to seating and friction are not applicable to pre-tensioning. Losses due to elastic shortening and relaxation of tendons, differ from those in the case of post-tensioning. These can be calculated as follows:

3.5.1 Elastic Shortening of Concrete The loss of stress (f_{PES} in MPa) in the prestressing steel in pre-tensioned girder shall be calculated as:

$$f_{pES} = \frac{\bar{E}_p}{E_{ci}} f_{cgp}$$

Where,

f_{cgp} = sum of concrete stresses at the centre of gravity of prestressing tendons due to the prestressing force at transfer and the self-weight of the member at the sections of maximum moment (MPa)

E_p = modulus of elasticity of prestressing steel (MPa)

E_{ci} = modulus of elasticity of concrete at transfer (MPa)

Note : The above method is different from that given in clause 11.1 of IRC:18 as unlike post-tensioning, all the strands are stressed at the same time and the forces transferred to the concrete simultaneously.

3.5.2. **Calculations of Losses due to Relaxation of Prestressing Steel :** In the case of pretensioned concrete, relaxation losses start as soon as the pretensioning is carried out, whereas, the effect of the same on the concrete begins only after the prestressing force is transferred to the concrete. In this regard, relaxation losses shall be calculated as per Table 4A and 4B of IRC:18 for assessment of actu- ally available prestressing force at transfer. In case of steam curing, variation of pattern of relaxation loss with temperature and time shall be assessed on the basis of appropriate specialist literature.

3.6. Cover and Spacing of Prestressing Steel

Requirements of cover of prestressing steel associated with pre-tensioned concrete shall be as per the provisions for untensioned reinforcement. Minimum centre to centre spacing of strands shall be 44mm and 51mm for 12.7 mm and 15.2 mm strands. However, precautions should be taken to locate prestressing strands in such a way that cutting of projecting strands at the ends of girders does not affect the projecting untensioned reinforcement, which is required to be bonded into the adjoining cast-in-situ concrete. In case the designs cater for utilization of bonded strands as passive reinforcement extending from precast girder into the adjoining cast-in-situ concrete, stress in the strands shall be limited to that in the adjoining reinforcing steel, in order to maintain strain compatibility. In such case, these strands shall not be cut.

3.7. Transmission Length of Tendons

The transmission length is defined as the length over which a tendon develops its full stress capacity through bond with the concrete.

The transmission length depends on a number of variables, the most important being:

(a) The degree of compaction of the concrete.
(b) The strength of the concrete.
(c) The size and type of tendon.
(d) The deformation (e.g. crimp) of the tendon.
(e) The stress in the tendon and
(f) The surface condition of the tendon.

The transmission lengths for the tendon, towards the top of a unit, is usually greater than those at the bottom.

Where the initial prestressing force is not greater than 90% of 0.1% proof stress of the tendon and where the concrete strength at transfer is not less than 30MPa, the transmission length shall be taken as follows :

$$l_t = \frac{k_t \Phi}{\sqrt{f_{ci}}}$$

Where

f_{ci} is the concrete strength at transfer (in MPa)

l_t is the transmission length (in mm)

Φ is the nominal diameter of the tendon (in mm)

k_t is a coefficient dependent on the type of tendon to be taken as 240 for 7 wire standard and super strand as per IS:14268

The development of stresses over the transmission length shall be assumed to vary linearly from zero at the start of the bonded portion to maximum stress at the end of transmission length.

If the tendons are prevented from bonding to the concrete near the ends of the units by the use of HDPE tubes, sleeves or tape, the transmission lengths should be taken from the ends of the debonded portions.

3.8. Development Length of Tendons

Pre-tensioned tendons shall be bonded beyond the point, where they are no longer required for stress control, to a distance equal to 40 times the nominal strand diameter.

3.9. Second Order Effects

In cases where simply supported precast girders are made continuous using diaphragm continuity, second order effect of creep redistribution due to change of the structural system from isostatic (simply supported) to hyperstatic (continuous) shall be accounted for. In addition, due to the difference of age of precast girders and that of the cast-in-situ deck slab, intrinsic stresses are developed on account of differential shrinkage. These shall be incorporated appropriately in the design.

Suggested method of calculating these second order effects is as follows:

Step 1:
Calculate Creep Factor φ = Residual Creep Strain/Elastic Strain
= Residual Creep Strain x E_{cj} / Elastic Stress
where E_{cj} = Elastic Modulus of girder concrete at the time of establishing continuity

NOTE : An increase or reduction of 15% on this value of φ should be taken to cater for unfavorable variations.

Step 2:
Calculate Creep Coefficient $\varphi_{cr} = 1 - e^{-\varphi}$

Step 3:
Calculate factor to account for effect of creep on differential shrinkage $\varphi_{sh} = \dfrac{(1-e^{-\varphi})}{\varphi}$

Step 4:
Apply those dead loads and prestressing on hyperstatic structure which were actually applied on isostatic structure.

Step 5:
Bending moments so obtained at the intermediate support are termed as restraint moments due to dead load M_{DR} and restraint moment due to prestress M_{PR}.

Step 6:
Calculate restraint moments M_{SH} due to differential shrinkage between cast-in-situ slab and precast girder, which occur on a hyperstatic structure, by any suitable method.

Step 7:
The final restraint moment (sagging) at any intermediate support shall be calculated as
$M_R = (M_{PR} - M_{DR}) \times \varphi_{cr} - M_{SH} \times \varphi_{sh}$

The final restraint moment diagram is assumed to vary linearly between supports with values of respective M_R at intermediate supports and zero at the end supports.

Step 8:
Add bending moments due to other effects such as DL, SIDL, LL, differential settlement etc (as they occur) to the M_R for the design purpose. Effect of eigen stress due to differential shrinkage shall also be accounted for.

Notes :

(i) Alternatively, any other method of calculating second order effects may be used based on appropriate specialist literature.

(ii) It should be kept in view that the above mentioned creep and shrinkage take place over a long period of time.

(iii) Calculation of safety at ultimate moments may exclude the above second order effects.

3.10. Continuity by Post-Tensioning

In case continuity is achieved using post tensioning, the prestress may be imparted to girder section alone, where loads of deck slab, diaphragm, SIDL, live loads etc. act on a continuous structure. Alternatively, prestress may be imparted after casting of deck slab and diaphragms, where the loads of deck slab and diaphragms only will act on simply supported structure and SIDL, live loads etc, will act on the continuous structure.

3.11. Additional Treatment at Girder-Diaphragm Interface

The girder- diaphragm interface is usually

located at a crucial location where shear forces are high and in case of continuous spans, bending moments are also high. At these interfaces, apart from adequate preparation of the construction joint, as illustrated elsewhere in this document, a suitably designed longitudinal reinforcement extending from the precast girder into the cast-in-situ concrete, adequate to withstand the shear force across the interface shall be provided. This reinforcement shall be in addition to the vertical shear reinforcement.

3.12. Confining Reinforcement

Bottom bulbs of pre-tensioned girders are highly stressed at the ends of bonded prestressing. To guard against the crushing failure of concrete, a reinforcement equal to atleast 10mm dia TOR @ 150mm c/c shall be provided in an appropriate shape to enclose the strands over a length of 1.5 times depth of the girder from the ends. Stirrups should be detailed not to be in contact with strands

3.13. Bursting Reinforcement

The bursting resistance of pre-tensioned anchorage zone provided by vertical reinforcement in the ends of pre-tensioned beams shall be taken as:

$P_r = f_s A_s$

Where:

f_s = stress in steel not exceeding 140 MPa

A_s = total area of vertical reinforcement located with in the distance h/5 from the end of the beam (mm^2)

h = overall depth of precast member (mm)

The bursting resistance P_r shall not be less than 4 percent of the prestressing force at transfer.

The end vertical reinforcement shall be as close to the end of the beam as practicable.

3.14. Losses of Prestress due to Steam Curing

Where steam curing is employed in the manufacture of prestressed concrete units, variations in the behavior of the material at higher than normal temperatures need to be considered. In addition, where the 'long-line' method of pre-tensioning is used, there may be additional losses as a result of bond developed between the tendon and the concrete when the tendon is hot and relaxed. Since the actual losses of prestress due to steam curing are a function of the techniques used by the various manufacturers, specialist advice should be sought.

3.15. Shear Connectors

Shear connectors between the mating surfaces of precast girder and cast-in-situ deck slab shall be designed as per the provisions of IRC:22.

3.16. Reinforcement to cater for Indirect Support

When the main beams are not directly supported by the bearing and are supported on the cross girder during service or during bearing replacement, suspension stirrups shall be provided to take up reaction applied by hanging action. This reinforcement shall be in addition to what is required from other structural considerations. The purpose of this reinforcement is to transfer the vertical shear from girder to top of the associated diaphragm. This reinforcement shall be designed using appropriate specialist literature.

3.17. Handling Stresses

Precast units should be designed to resist, without permanent damage, all stresses induced by handling, storage, transportation and erection. The position of lifting and supporting points should be specified. The design should take account of the effect of lifting and placing on to supports. All locations of high concentration of stresses in precast members as well as the concrete members (over which the precast members are supported temporarily or permanently) should be provided with closely spaced reinforcement mesh, close to the surface of contact to prevent local crushing of concrete.

4. CONSTRUCTION REQUIREMENTS

Minimum cement content, maximum water-cement ratio and other durability requirements shall be the same as indicated in Table 5 of IRC:21

except minimum grade of concrete, which shall be M40 for pre-tensioned girders.

4.1 Precasting

All sides, bottoms and header forms shall be of steel or any other suitable material. Forms shall be of sufficient thickness, with adequate external bracing and shall be stiffened and adequately anchored to withstand the forces due to placement and vibration of concrete. All joints of form work shall be leak proof. The bottom shutter shall have arrangement to permit longitudinal movement of girder concrete, which happens while imparting prestress. Identifying marks shall be placed on the girders to indicate the correct orientation to ensure correct debonding locations, which may not be symmetrical, longitudinally.

Compaction of concrete may be achieved through needle vibrators or form vibrators along with needle vibrators. For casting of precast beams, any of the two commonly known techniques of precasting viz. (i) Long Line method or (ii) Short Line method may be used. It shall be ensured that tolerances mentioned in para 4.10 are strictly adhered to.

The girders shall not be moved from the casting location until stipulated strength requirements have been attained. The concrete shall have attained a minimum compressive strength of 20 MPa at the time of removal of forms. Curing of concrete may be achieved through water or steam followed by water curing. Approved curing compound may also be used

Longitudinal movement of the girders that takes place while releasing the prestress shall be suitably catered for. In case of long line method of precasting, adequate longitudinal gap shall be provided between girder ends during precasting to accommodate projecting reinforcement and required length of the projecting strands.

4.2. Pretensioning Operation

Pretensioning of strands may be carried out either using single pull jack or multi pull jack. In case of the former, it shall be ensured, at each stage, that the strands are stressed symmetrically, so that the supporting system of the strands does not rotate or distort. This may be achieved through suitably designed moving trolley engaging the strands or any other suitable arrangement. Prestressing force shall be transferred to metallic spacer, trolley, etc. so that the force does not remain on the hydraulic system for long.

It is necessary to apply a small prestressing force, through hydraulic jacks to remove slackness of the strands. After removal of the slackness, the strands must be thoroughly examined to ensure correct alignment, including that of the debonding tubes. Reference marks for measuring elongation shall then be established and the full strand load is applied thereafter. Loads indicated by gauging system shall control the tensioning, with elongation checked on every strand.

It shall be ensured that the entire length of each strand between the grips is free of any defects. This is of particular importance while precasting girders using long line method entailing, longer pieces of strands between the grips.

4.3. Detensioning of Strands

Detensioning, in order to impart the prestress, shall be effected gradually, so that there is no significant loss of bond due to slippage of strands and consequent increase in the transmission length. For detensioning, the trolley is pulled outward by a small distance, in order to release the metallic spacers, before releasing the prestressing force. Even when the pre-tensioning is carried out through single pull jack, the release of the force in all the strands, while imparting the prestress to the concrete, shall be simultaneous. It shall be ensured that, during this process, prestressing forces at any stage does not exceed 90% of 0.1% proof stress.

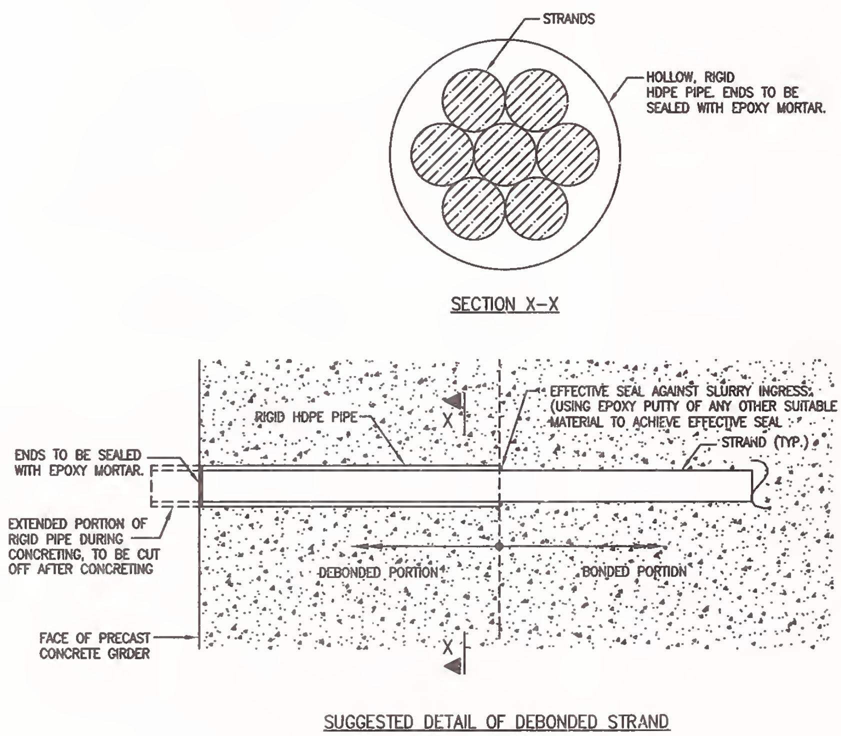
4.4 Cutting of Strands

Cutting of strands is an important operation in case of pre-tensioned girders because they are in close proximity with the untensioned reinforcement which is required to be extended into the adjoining cast-in-situ concrete. Diamond bit saw shall be used to cut the strands. Strands and untensioned reinforcement shall be so arranged that the untensioned reinforcement and those strands which are required to be extended into the adjoining cast-in-situ concrete, do not get affected during cutting operation.

Under factory conditions, flame cutting may be resorted to. Yellow flame should be used first to heat the strand without introducing undue stresses and then blue flame for the actual cutting. Heat cutting of strands shall be carried out symme-trically about the vertical axis of the members. One strand at a time on each side of the vertical axis for all girders in a long line shall be cut. The next two strands of all the girders shall be cut in the same manner. The above process shall be repeated till all the strands are cut. This will ensure gradual uniform transfer of prestress to girders.

4.5 Debonding of Strands

Debonding of strands, wherever required, shall be carried out using HDPE debonding tubes. PVC tubes shall not be permitted for this purpose. After pretensioning the strands and before concreting, a recheck shall be made to ensure that the debonding tubes are placed at the intended locations. Both ends of the debonding tubes shall be effectively sealed against ingress of any cement slurry using epoxy putty or any other suitable material. Fig. 6 depicts a possible arrangement of debonding.



REFERENCE PARA : 3.5

Fig. - 6 Typical Detail of Debonded Strand

4.6. Concreting

A fully automated, computer-controlled batching plant shall be used. The batching plant shall be provided with moisture measuring and compensating devices and automatic pump for dispensing admixtures.

Sampling and testing of concrete shall be as per the provisions of IRC:21. Additional cubes shall be prepared to determine the concrete strength at the time of removal of forms and transfer of prestress. Adequate number of samples shall be taken for this purpose, which shall be cured in identical conditions to those of the concrete of respective girders.

4.7 Surface Preparation

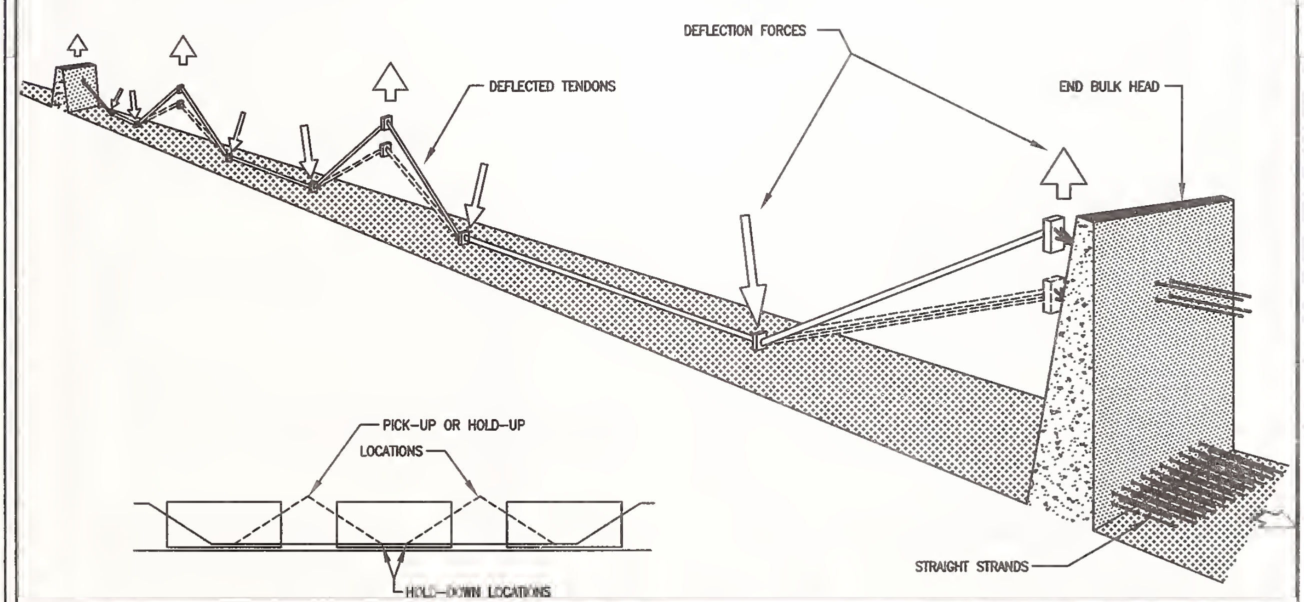
All surfaces, coming in contact with deck slab/diaphragm shall be adequately prepared by green cutting, using surface retarders, or by mechnical means to remove the laitance and just expose the aggregates. Usually, precast girders

join the cast-in-situ concrete of end diaphragms at the points of high shear stress. Therefore, it is extremely important to adequately prepare the end faces of the girders for effective bonding with the new concrete. This shall be done using suitable mechanical means (such as 100% hacking) to ensure that the course aggregates are just exposed. Surface retarders, may also be used for this purpose.

4.8 Deflected Tendons

An effective way of making long span pre-tensioned girder feasible is to use deflected tendons instead of the conventional straight tendons. This requires the use of hold-up/ hold-down devices at each deflection location, in order to hold the tendons in the desired profile and location. A hold-down device normally consists of rollers attached to a vertical rod, which passes through the bottom form and is anchored to the form substructure or foundation to resist the vertical component of the prestress force. The force which must be resisted by the hold-up / hold-down device, and therefore its size, depends on the number of deflected strands and the trajectory angle of the strands.

One method of producing deflected tendon profile is to use hold-up / hold-down devices to raise the profile of the strand at the ends of beams and then tension the strands in their already deflected profile. Other method is to hold-up / hold-down the strand to the proper elevation after tensioning the strands. Again, the number of deflected strands and their angle directly influence the size and cost of the hold-up / pick-up device. Fig. 7 shows a typical deflected strand profile in a prestressing bed.



REFERENCE PARA : 3.8

Fig. - 7 Arrangement for Deflection of Tendons

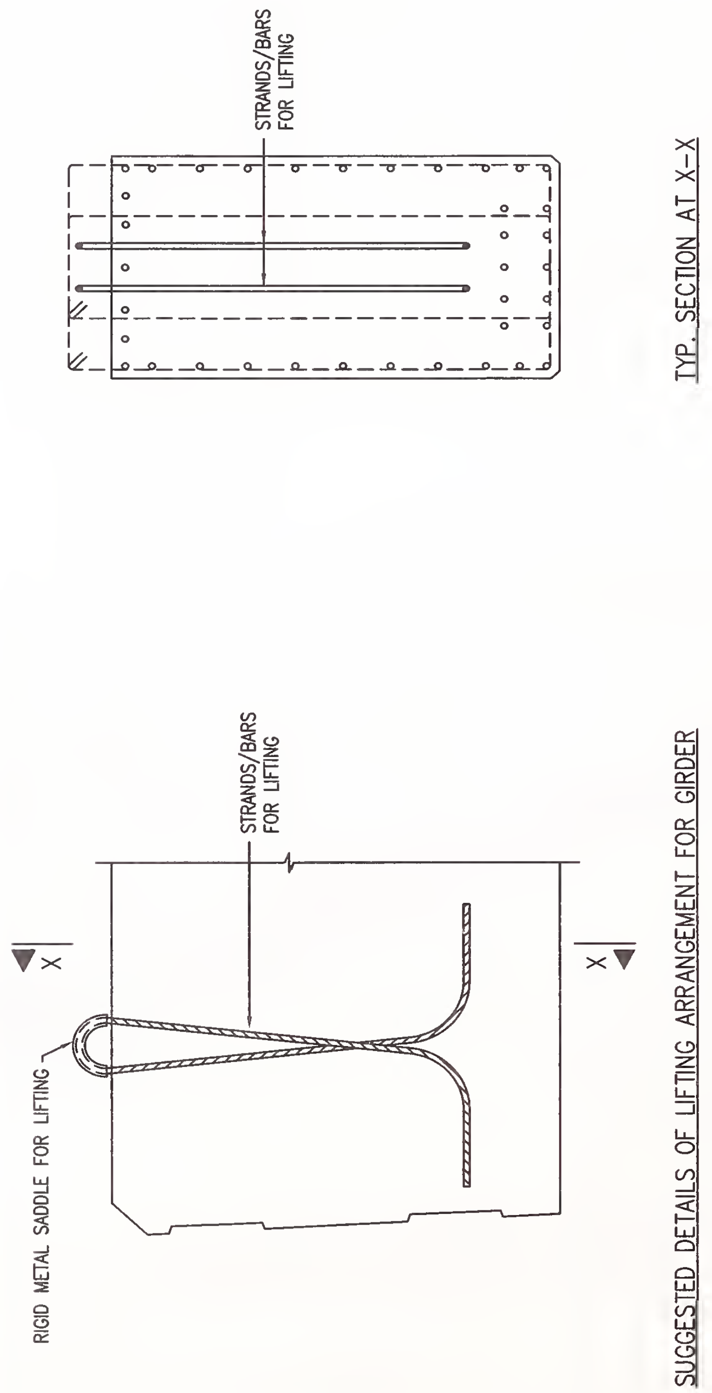
For single tendons, the deflector in contact with the tendon, should produce a radius of not less than 5 times the tendon diameter for wire or 10 times the tendon diameter for strand and total angle of deflection should not exceed 15°.

4.9 Handling and Transportation of Precast Girders

Handling of precast girders from precasting location to the bridge site requires careful

operation. Lifting locations shall be strictly as indicated on the construction drawings. Fig. 8 depicts typical details of lifting hook.

Lifting devices generally consist of loops of prestressing strand or mild steel bars or any other suitable arrangement. If it is anticipated that



REFERENCE PARA : 3.9

Fig. - 8 Typical Lifting Arrangement of Girder

embedded material for lifting devices will be cast into the face of a member that will be exposed to view or to corrosive materials in the completed structure, the depth of removal of the embedded material and method of filling the cavities after removal shall be as shown on the construction drawings. The depth of removal shall not be less than the clear cover required to the reinforcing steel. The cavity so formed shall be suitably grouted for protecting the embedded metal. Also, the projecting reinforcement shall be suitably protected against corrosion.

Method of transportation should be planned in such a way that the vehicle employed to transport the long girders can successfully negotiate the available road geometry. Adequate care shall be taken to ensure that the girder being transported does not topple due to unstable arrangement. For this purpose, height of vehicle shall be kept as low as possible. This will also help in accommodating greater height of the system during transportation below existing bridges or through any other constraints. Girders should be transported only after 28 day concrete strength is achieved.

4.10. Recommended Dimensional Tolerances forPrecast Girders

Length	$\pm$ 10mm
Flange width & thickness	$\pm$ 5mm
Depth	$\pm$ 5mm
Web thickness	$\pm$ 3mm
Position of tendons	$\pm$ 3mm
Maximum surface roughness =	1.5mm on 3.0m template

4.11. Quality Control

To ensure that the drawings and specifications are truly followed, inspection personnel and a regular programme of inspecting all aspects of production should be provided. Although production perso- nnel should be responsible for quality of products, a system of checks and balances should be in place to ensure review of all materials and processes. Complete record of inspection and testing shall be maintained. Periodical calibration of relevant equipments shall be carried out. Load test, to destruction, of precast girder may be carried out, if specifically provided for in the contract.

REFERENCES

In this publication reference to the following Standards of IRC, IS, BS AASHTO Specifications, EURO CODE besides Guidelines from BCA, PCA and PCI have been made. At the time of publication, the editions indicated were valid. All standards and guidelines are subject to revisions and the parties to agreements based on these guidelines are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below :

1. IRC:18-2000 — Design Criteria for Prestressed Concrete Road Bridges (Post-Tensioned Concrete) (Third Revision)
2. IRC:21-2000 — Standard Specifications and Code of Practice for Road Bridges, Section III Cement Concrete Plain & Reinforced (Third Revision)
3. IRC:22-1986 — Standard Specifications and Code of Practice for Road Bridges, Section VI Composite Construction (First Revision) (Reprinting 2005)
4. BS:5400 Part 4-1990 — Steel, Concrete and Composite Bridges:Code of Practice for Design of Concrete Bridges
5. IS:14268-1995 — Specifications for Uncoated Stress relieved Relaxation Seven Ply Strand for Prestressed Concrete (Reaffirmed 2003)
6. EURO Code 2 — Design of Concrete Structures pr En 1992-1 (Final Draft): October 2001
7. AASHTO LRFD — Bridge Design Specifications

Publications

1. ***British Cement Association :***
   Composite Concrete Bridge Superstructures
2. ***Portland Cement Association :***
   Design of Continuous Highway Bridges with Precast, Prestressed Concrete Girders.
3. ***Precast/Prestressed Concrete Institute :***
   Precast / Prestressed Concrete Short Span Bridges.

(The official amendments to this document would be published by the IRC in its periodical, 'Indian Highways' which shall be considered as effective and as part of the code/guidelines/manual, etc. from the Date specified therein)